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Spin structure of nucleon and
spin transfer in high energy fragmentation process

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Spin transfer in high energy fragmentation process is determined by the hadronization mechanism and spin structure of hadrons. It can be studied by measuring the polarizations of hyperons and/or vector mesons in e^+e^- annihilation, in the current fragmentation region of polarized deeply inelastic lN-scatterings, and high p_T-jets in polarized pp-collisions. Theoretical calculations have been made using different models. In this talk, I will briefly summarize the main features of the models, the results obtained and the comparison with available data. They can be used for future tests by experiments.

Keywords: Spin transfer; nucleon spin structure; hadronization.

1. Introduction

In this talk, I would like to use this opportunity to stress one problem that we met in studying the polarization of hadrons produced in high energy reactions.
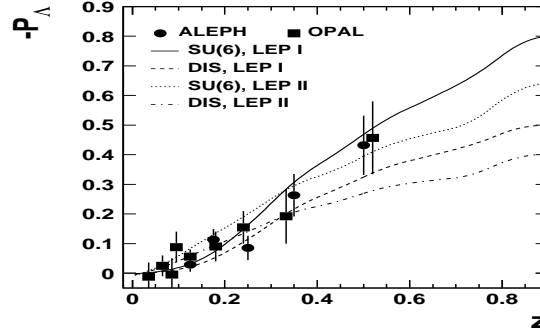
It is now well-known that, for the spin compositions of nucleon, we have two kinds of results: One is obtained from the SU(6) wave-function, the other from the polarized deeply inelastic lN scattering data and other related knowledges. We denote them by SU(6) and DIS pictures in the following. I would like to emphasize that both of them can be extended to other baryons in the same flavor SU(3) octet as the nucleon.[1] This is because in obtaining the DIS results for nucleon, we have already used the flavor SU(3) symmetry. The results can be found in different literature, e.g., table 1 of [2], which I include also here (table 1). We see that these results are very much different from each other. We have therefore a very practical question: Which should we use when we calculate the polarization of hadrons produced in high energy reactions from the polarizations of quarks? There exist two classes of theoretical treatments: One of them simply uses SU(6), the other uses DIS. But there is no discussion about the question which should be used before [2].

In [2], we first explicitly pointed out the problem and showed that Λ in e^+e^- annihilation at the Z^0 pole is an ideal place to study it. We made the calculations on Λ polarization using the DIS picture, compared the results with those from SU(6) obtained by Gustafson and Häkkinen earlier [3], and the available data from ALEPH

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Table 1.   Sin compositions of quarks in the octet baryons. (See [2] for details.)

			$SU(6)$	DIS			$SU(6)$	DIS
ΔU		$(\Sigma + D)/3 + F$	4/3	0.79		$(\Sigma - 2D)/3$	-1/3	-0.47
ΔD	p	$(\Sigma - 2D)/3$	-1/3	-0.47	n	$(\Sigma + D)/3 + F$	4/3	0.79
ΔS		$(\Sigma + D)/3 - F$	0	-0.12		$(\Sigma + D)/3 - F$	0	-0.12
ΔU		$(\Sigma - D)/3$	0	-0.17		$(\Sigma + D)/3$	2/3	0.36
ΔD	Λ	$(\Sigma - D)/3$	0	-0.17	Σ^0	$(\Sigma + D)/3$	2/3	0.36
ΔS		$(\Sigma + 2D)/3$	1	0.62		$(\Sigma - 2D)/3$	-1/3	-0.44
ΔU		$(\Sigma + D)/3 + F$	4/3	0.82		$(\Sigma + D)/3 - F$	0	-0.01
ΔD	Σ^+	$(\Sigma + D)/3 - F$	0	-0.10	Σ^-	$(\Sigma + D)/3 + F$	4/3	0.82
ΔS		$(\Sigma - 2D)/3$	-1/3	-0.44		$(\Sigma - 2D)/3$	-1/3	-0.44
ΔU		$(\Sigma - 2D)/3$	-1/3	-0.44		$(\Sigma + D)/3 - F$	0	-0.10
ΔD	Ξ^0	$(\Sigma + D)/3 - F$	0	-0.10	Ξ^-	$(\Sigma - 2D)/3$	-1/3	-0.44
ΔS		$(\Sigma + D)/3 + F$	4/3	0.82		$(\Sigma + D)/3 + F$	4/3	0.82

Fig. 1. P_Λ in $e^+e^- \to \Lambda X$. The data are for LEP I [4,6]. The figure is taken from [5].

[4] and later [5] also those from OPAL [6] (see Fig.1). We found that the data can unfortunately not be able to distinguish between the two pictures although it seems that the SU(6) results fit the data better. We therefore made a systematical study [2,5,7] for different cases in this connection. In the following, I will briefly summary the results obtained. They can be used for further tests by future experiments. Similar calculations have also been carried out by other groups [e.g. 8-11].

2. The calculation method

To test different pictures for spin transfer in the fragmentation process $q(pol) \to h + X$, we need: (1) to produce a q beam with known polarization, (2) to measure the polarization of h. Hence, hyperon polarizations (P_H) in the following three cases are best suitable: (a) $e^+e^- \to Z^0 \to HX$; (b) current fragmentation region in polarized $lN \to l'HX$; (c) high p_T jets in polarized pp collisions. This is because, here we can (i) separate fragmentation from the others, (ii) calculate the polarization of the quark before fragmentation, (iii) measure the polarizations of hyperons easily.

To calculate P_H in $q(pol) \to H + X$, we divide the produced H into the following four groups: (A) directly produced and contain the initial q; (B) directly produced

but do not contain the initial q; (C) decay contribution from heavier hyperons H_j that are polarized; (D) decay contribution from H_j that are unpolarized. That is,

$$D_q^H(z) = D_q^{H(A)}(z) + D_q^{H(B)}(z) + D_q^{H(C)}(z) + D_q^{H(D)}(z), \tag{1}$$

where $D_q^H(z)$ is the fragmentation function. Similarly, for polarized case, we denote, $\Delta D_q^H(z) \equiv D_q^H(z,+) - D_q^H(z,-)$, (the $+$ or $-$ means that the produced H is polarized in the same or opposite direction as the initial q), and we have,

$$\Delta D_q^H(z) = \Delta D_q^{H(A)}(z) + \Delta D_q^{H(B)}(z) + \Delta D_q^{H(C)}(z) + \Delta D_q^{H(D)}(z). \tag{2}$$

Clearly, there is no contribution for group (D) to ΔD, and it is assumed [2,3] that there is no contribution from group (B) either. Hence, we have,

$$\Delta D_q^{H(A)}(z) = t_{H,q}^F D_q^{H(A)}(z), \qquad \Delta D_q^{H(B)}(z) = 0,$$
$$\Delta D_q^{H(C)}(z) = \sum_j t_{H,H_j}^D \Delta D_q^{H_j}(z), \quad \Delta D_q^{H(D)}(z) = 0. \tag{3}$$

Here $t_{H,q}^F$ is the fragmentation spin transfer factor and is taken as $t_{H,q}^F = \Delta Q^H / n_q$, where ΔQ^H is the fractional contribution of spin of quark of flavor q to H as given in table 1, n_q is the number of valence quarks of flavor q in H. Clearly ΔQ^H is different in SU(6) or DIS picture. This is the place where different pictures come in. t_{H,H_j}^D is the decay spin transfer factor in $H_j \to H + X$. It is determined by the decay and is independent of the pictures for spin transfer in fragmentation.

Here, I would like to emphasize the following two points.

First, the classification of H into the above-mentioned four groups is independent of the polarization. All the $D_q^{H(\alpha)}$'s can be calculated using our knowledge on hadronization in unpolarized case. In fact, in the Feynman-Field-type of cascade fragmentation models, (A) is just the first rank hadron and the z-distribution $D_q^{H(A)}(z)$, usually denoted by $f_q^H(z)$ is a basic input of the model. Practically, all of them can be easily calculated using a Monte-Carlo event generator. The results are quite stable. Hence, the z-dependence of P_H in this model is empirically known without any input in connection with polarization effects. This is a good point to test the model. In Fig.1, we see that although different pictures lead to different P_Λ but the z-dependence is essentially the same, and it is also in agreement with the data. This is a strong support of the calculation procedure presented above.

Second, for decay contribution, presently, we have data on t_{H,H_j}^D for $J^P = (1/2)^+$ octet H_j's. Hence there is little uncertainty here. But for decuplet hyperons, there is neither data for t_{H,H_j}^D nor ΔQ^H in DIS picture. We can only make a rough estimation by invoking the simple quark model for both of them. There is a strong model dependence, especially for ΔQ^H, the estimation is definitely too crude. Hence, to make a good test of different pictures for spin transfer in fragmentation, we should choose the places to avoid the contribution from decuplet hyperon decay.

3. Results and discussions

(I) $e^+ e^- \to HX$: Results for different hyperons have been obtained [2,5]. We would like to have flavor separation in particular for u or d to Λ. We found that it is

impossible to do it in e^+e^- annihilation at Z-pole where $s \to \Lambda + X$ dominates.

(II) Polarized $e^-N \to e^-HX$ or $\nu_\mu N \to \mu^-HX$: Here, we have almost automatic flavor separation since $u \to H + X$ dominates the current fragmentation regions, and we have the advantage to study both longitudinally and transversely polarized cases in e^-N collisions. I would like to emphasize the following two points showed by the results: (1) There is a quite large contribution from heavier hyperon decay to Λ in these reactions and the final result for P_Λ is small in most cases. In particular, in $\nu_\mu N \to \mu^-HX$, we have a significant contribution from $\Lambda_c \to \Lambda X$, the spin transfer from which is completely unknown. Hence it is *not* a good choice to use Λ in these reactions to test different pictures. In contrast, there is almost no contribution from heavier hyperon decay to Σ^+ and $P_{\Sigma+}$ is large. (2) In the energy region of the presently available experiments such as HERMES[12] and NOMAD[13], it is impossible to separate the struck quark fragmentation from the target remnant contribution. In fact, the target remnant contributions dominate even in the middle of the so-called current fragmentation region in this case [7]. It is thus difficult to use these data to test the different pictures. One has to go to higher energies.

(III) Polarized $pp \to HX$ at high p_T: Here we reached similar conclusions as in (II), i.e., the contributions from heavier hyperon decay to Λ is high and it is more suitable to use $p(pol)p \to \Sigma^+X$ to test different pictures. For details, see [7].

Besides, we found that spin alignments of vector mesons can also provide useful information in this connection. Data from LEP exits, calculations have been made and compared with them. Further predictions for deeply inelastic lN scattering or pp collisions have been made. Interested readers are referred to [14] and the references cited there.

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